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Bacterial dominance of phototrophic communities in a High Arctic lake and its implications for paleoclimate analysis

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Abstract

The phototrophic communities in meromictic, perennially ice-covered Lake A, on Ellesmere Island in the Canadian High Arctic, were characterized by pigment analysis using high performance liquid chromatography. Samples were taken to determine the vertical changes down the water column as well as a variation between years. These analyses showed that Lake A had distinct phototrophic communities in its oxic and anoxic layers. The pigment analyses indicated that phototrophic biomass in the upper, oxic waters was dominated by picocyanobacteria, while in the lower, anoxic layer photosynthetic green sulphur bacteria were dominant. Interannual variation in pigment concentrations was related to the penetration of photosynthetically active radiation in the water column, suggesting that light availability may be limiting the net accumulation of photosynthetic bacterial biomass in Lake A. Pigment analysis of the surface sediments indicated that deposition was dominated by the photosynthetic sulphur bacterial contribution. The sedimentary record of bacterial pigments in polar meromictic lakes offers a promising tool for the reconstruction of past changes in ice cover and therefore in climate.

Keywords: Arctic; HPLC; Meromictic lake; Photosynthetic bacteria; Pigments

1. Introduction

Polar ecosystems are highly susceptible to disturbance by environmental change (ACIA, 2005). Climate models predict that warming over the next century will be amplified in the polar regions, with the most extreme temperature increases in spring and autumn (Anisimov et al., 2007; Turner et al., 2007). As a result of their sensitivity to perturbation, Arctic lakes will likely experience substantial future changes in their ecosystem properties including ice cover, light conditions, hydrological regimes, seasonality, trophic status and biological community structure (Rouse et al., 1997; Anisimov et al., 2007; Vincent and Laybourn-Parry, 2008).

The lakes of northwestern Ellesmere Island in the Canadian High Arctic are subject to pronounced

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annual extremes in their physical conditions, including temperature and photoperiod, that profoundly alter the conditions for lake biota. The severity of conditions in this region is comparable to polar desert sites in Antarctica such as the McMurdo Dry Valleys and the Vestfold Hills (Wharton et al., 1993; Gibson, 1999), with thick, perennial ice covers, annual precipitation below 150 mm, year round surface water temperatures near the freezing point, and several months per year without sunlight. Accordingly, there are numerous analogies between lakes from northern Ellesmere Island and these Antarctic regions (Vincent et al., 2008a). Meromictic lakes (i.e., lakes that are perennially stratified as a result of salt-dependent density gradients) have been identified from both polar regions, including several on northern Ellesmere Island (Hattersley-Smith et al., 1970; Pienitz et al., 2008) that formed after isostatic rebound caused the separation of fiord basins from the Arctic Ocean (Ludlam, 1996). These lakes are characterized by the presence of ice cover through all or most of the year, which controls mixing regimes, the penetration of solar radiation, and maintenance of stratification, among other properties (Doran et al., 1996; Gibson, 1999; Belzile et al., 2001). Presently, the ice thickness of northern Ellesmere Island lakes is on the order of 1.5–2 m, although nearby Ward Hunt Lake has an ice cover of ~4 m (Antoniades et al., 2007), and ice covers exceeding 5 m have been observed elsewhere on Ellesmere Island (Blake, 1989). While ice is seasonal in the majority of Arctic lakes, and typical Ellesmere Island lakes are ice-covered for over 10 months per year, several northern Ellesmere Island lakes including Lake A have perennial ice cover. It has, however, been hypothesized that even these lakes are now in transition to seasonal ice regimes due to climate warming (Van Hove et al., 2006).

Past research in Lake A has focused on its geochemistry (Jeffries et al., 1984; Jeffries and Krouse, 1985; Gibson et al., 2002), physical properties (Belzile et al., 2001; Van Hove et al., 2006), biology (Van Hove et al., 2001, 2008) and, more recently, on modelling patterns of thermal stratification (Vincent et al., 2008b) and sedimentology in the lake basin (Tomkins et al., 2009). This research has revealed that Lake A has a deepwater thermal maximum, both sharp and diffuse deepwater peaks in geochemical profiles, the presence of photosynthetic sulphur bacteria and the sedimentation of inorganic pyrite framboids. While Lake A has been more extensively studied than the large majority of polar lakes, many details of its biological and physical processes remain unknown.

Signature pigments from anaerobic photosynthetic bacteria have been applied in numerous paleoecological studies, including in polar lakes (Hodgson et al., 2004). Although they have largely been used to reconstruct variability in past oxic status and productivity, these changes often have climatic implications. Okenone, a marker pigment for purple sulphur bacteria, has been used to infer periods of stratification and meromixis in temperate and high latitude sites (e.g., McIntosh, 1983; Guilizzoni et al., 1986; Schmidt el al., 1998; Anderson et al., 2008; McGowan et al., 2008). Pigments from green sulphur bacteria, primarily isorenieratene, have been used to reconstruct past oxic and trophic characteristics in both marine and freshwater environments (McIntosh, 1983; Repeta, 1993; Mallorquí et al., 2005; Squier et al., 2005; Tani et al., 2009). Transformation products of isorenieratene and okenone have been used in studies of the evolution of ocean oxygen content (Brocks and Pearson, 2005), and have been identified from samples as old as the Paleoproterozoic (Brocks et al., 2005). In Lake A, we tested the hypothesis that bacterial photopigments might be reflective of the degree of ice cover, given the ice-dominated character of the lake and the role of ice in determining light penetration (Belzile et al., 2001). We further hypothesized that bacterial pigments preserved in the sediments might be developed as a new indicator of past ice cover in paleoecological reconstructions, a method that could then be applied in other ice-dominated meromictic lakes.

Our objectives, therefore, were to understand the phototrophic characteristics of Lake A's water column through high performance liquid chromatography (HPLC) examination of photosynthetic pigments, and to study the sedimentary deposition of photosynthetic pigments in order to evaluate the utility of this new application for the reconstruction of past ice cover and climate.

2. Materials and methods

2.1. Physical setting

Lake A is located along the northern coast of Ellesmere Island in Quttinirpaaq National Park (83°00′ N, 75°30′ W; Fig. 1). It lies approximately 4 m above sea level, with a maximum known depth of 128 m, a surface area of 4.9 km^2, and a catchment of 37 km^2 (Jeffries et al., 1984; Van Hove et al., 2006). Lake A is perennially ice-covered. Previous studies have shown that ice thickness was stable between 1969 and 1999, with early summer thickness measurements of ~2 m